ARTIFICIAL INTELLIGENCE GUIDED IN-SITU PIEZOELECTRIC SENSING FOR CONCRETE STRENGTH MONITORING

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Developing a reliable in-situ non-destructive testing method to determine the strength of in-place concrete is critical because a fast-paced construction schedule exposes concrete pavement and/or structures undergoing substantial loading conditions, even at their early ages. Conventional destructive testing methods, such as compressive and flexural tests, are very time-consuming, which may cause construction delays or cost overruns. Moreover, the curing conditions of the tested cylindrical samples and the in-place concrete pavement/structures are quite different, which may result in different strength values. An non-destructive testing (NDT) method that could directly correlate the mechanical properties of cementitious materials with the sensing results, regardless of the curing conditions, mix design, and size effect is needed for the in-situ application.

The piezoelectric sensor-based electromechanical impedance (EMI) technique has shown promise in addressing this challenge as it has been used to both monitor properties and detect damages on the concrete structure. Due to the direct and inverse effects of piezoelectric, this material can act as a sensor, actuator, and transducer. This research serves as a comprehensive study to investigate the feasibility and efficiency of using piezoelectric sensor-based EMI to evaluate the strength of newly poured concrete. To understand the fundamentals of this method and enhance the durability of the sensor for in-situ monitoring, this work started with sensor fabrication. It has studied two types of polymer coating on the effect of the durability of the sensor to make it practical to be used in the field.

The mortar and concrete samples with various mix designs were prepared to ascertain whether the results of the proposed sensing technique were affected by the different mixtures. The EMI measurement and compressive strength testing methods (ASTM C39, ASTM C109) were conducted in the laboratory. The experimental results of mortar samples with different water-to-cement ratios (W/C) and two types of cement (I and III) showed that the correlation coefficient (R^2) is higher than 0.93 for all mixes. In the concrete experiments, the correlation coefficient between the EMI sensing index and compressive strength of all mixes is higher than 0.90. The empirical estimation function was established through a concrete slab experiment. Moreover, several trial implementations on highway construction projects (I-70, I-74, and I-465) were conducted to monitor the real-time strength development of concrete. The data processing method and the reliable index of EMI sensing were developed to establish the regression model to correlate the sensing results with the compressive strength of concrete. It has been found that the EMI sensing method and its related statistical index can effectively reflect the compressive strength gain of in-place concrete at different ages.

To further investigate the in-situ compressive strength of concrete for large-scale structures, we conducted a series of large concrete slabs with the dimension of 8 feet × 12 feet × 8 inches in depth was conducted at outdoor experiments field to simulate real-world conditions. Different types of compressive strength samples, including cast-in-place (CIP) cylinder (4" × 6") – (ASTM C873), field molded cylinder (4" × 8") – (ASTM C39), and core drilled sample (4" × 8") – (ASTM C42) were prepared to compare the compressive strength of concrete. The environmental conditions, such as ambient temperatures and relative humidity, were also recorded. The in-situ EMI monitoring of concrete strength was also conducted. The testing ages in this study were started from 6 hours after the concrete cast was put in place to investigate the early age results and continued up to 365 days (one year) later for long-term monitoring. The results indicate that the strength of the CIP sample is higher than the 4" x 8" molded cylinder, and that core drilled concrete is weaker than the two aforementioned. The EMI results obtained from the slab are close to those obtained from CIP due to similar curing conditions. The EMI results collected from 4 × 8-inch cylinder samples are lower than slab and CIP, which aligns with the mechanical testing results and indicates that EMI could capture the strength gain of concrete over time.

The consequent database collected from the large slab tests was used to build a prediction model for concrete strength. The Artificial Neuron Network (ANN) was investigated and experimented with to optimize the prediction of performances. Then, a sensitivity analysis was conducted to discuss and understand the critical parameters to predict the mechanical properties of concrete using the ML model. A framework using Generative Adversarial Network (GAN) based on algorithms was then proposed to overcome real data usage restrictions. Two types of GAN algorithms were selected for the data synthesis in the research: Tabular Generative Adversarial Networks (TGAN) and Conditional Tabular Generative Adversarial Networks (CTGAN). The testing results suggested that the CTGAN-NN model shows improved testing performances and higher computational efficiency than the TGAN model. In conclusion, the AI-guided concrete strength sensing and prediction approaches developed in this dissertation will be a stepping stone towards accomplishing the reliable and intelligent assessment of in-situ concrete structures.